

# **EVALUATION OF SLOPE STABILITY FOR WASTE ROCK DUMPS IN A MINE**

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF

**Bachelor of Technology  
In  
Mining Engineering**

By

**CHARANPREET SINGH FLORA**  
10505021



Department of Mining Engineering  
National Institute of Technology  
Rourkela-769008  
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Under the Guidance of  
**Dr. MANOJ KUMAR MISHRA**



Department of Mining Engineering  
National Institute of Technology  
Rourkela-769008  
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**National Institute of Technology  
Rourkela**

**CERTIFICATE**

This is to certify that the thesis entitled “*EVALUATION OF SLOPE STABILITY FOR WASTE ROCK DUMPS IN A MINE* ” submitted by Sri Charanpreet Singh Flora, Roll No. 10505021 in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

**(Dr. MANOJ KUMAR MISHRA)**

## **ACKNOWLEDGEMENT**

My heart pulsates with the thrill for tendering gratitude to those persons who helped me in completion of the project.

The most pleasant point of presenting a thesis is the opportunity to thank those who have contributed to it. Unfortunately, the list of expressions of thank no matter how extensive is always incomplete and inadequate. Indeed this page of acknowledgment shall never be able to touch the horizon of generosity of those who tendered their help to me.

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An assemblage of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them.

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**Charanpreet Singh Flora**

DATE:  
PLACE:

Dept. of Mining engineering  
National Institute of Technology  
Rourkela – 769008

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## **ABSTRACT**

The growing needs have been pushing the limits, to which the mining industry has to reach to lift itself to fulfill the demand. The effect can be seen from the methods of mining that have evolved over the years. The heavy machinery adopted for the extraction has been producing wastes in the form of waste rocks whose management is again of prime importance. The issues relating to the stability of these overburden dumps is catching attention worldwide from quite some time, which is quite important for the safe working in and around these monstrous structures as well as restricted availability of land. This paper deals with the stability issues of dumped slopes for a local chromite mine. The analysis cover analysis of various sections of the waste dumps from the mine including material properties, strength values, bench height and angle.

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# CHAPTER: 01

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# **INTRODUCTION**

Aim of the Study

Methodology

Layout

## **CHAPTER - 1**

### **1.0 INTRODUCTION**

In recent years, there are numbers of landslide occur everywhere. Most of the landslide happens on the cut slopes or embankment along roads, highway and sometimes within the vicinity of highly populated residential area especially those in the highly terrain. Thus, a proper understanding, monitoring and management of slope stability are essentially important to minimize the severity or casualty in any landslide.

The growing needs have been pushing the limits, to which the mining industry has to reach to lift itself to fulfill the demand. The effect can be seen from the methods of mining that have evolved over the years. The heavy machinery adopted for the extraction of the minerals has been producing huge wastes in the form of waste rocks, the management of which is again of prime importance. The issues relating to the stability of these overburden dumps is catching attention worldwide from quite some time, which is quite important for the safe working in and around these monstrous structures.

The various techniques are applied for the extraction of the minerals, but mostly the most common practice has been the drilling and blasting. This practice produces the overburden or waste rocks. These waste rocks are transported from the mines to the waste rock dumping sites

As the mine expands over a period of time, so do these waste dumps and the issues regarding their stability become important. To deal with these slope stability issues various approaches have been adopted and developed over the years. The approaches now have been more of computational rather than the manual. Various softwares are available to analyse the slopes that are liable to failure by the calculating the factor of safety.

Generally, there are a numbers of on the shelf slope stability analysis software available in the market. Although, all of them are capable to analyze the stability of slope, their user friendliness and the accuracy of the result will varies from each other. In this project, FLAC/SLOPE and GALENA Software will be use to analyze a numbers of complex slope.

**1.1 Aim of the Study:** The goal of the present investigation is to achieve safe operation of the opencast mine. This is achieved by addressing the following specific objectives.

#### 1.1.1 Specific Objectives:

The primary objective of this project is to comment on the stability of the slopes constructed due to dumping of the overburden matter during removal process. This aspect has the following specific objectives:

- Collection of the samples from the field

- The analysis of these samples to find out parametric variations affecting the slope stability as the cohesion, angle of friction, density and other parameters.
- Utilisation of the results of sample collected to predict the stability in terms of safety factor
- Determination of the factor of safety of the various slopes using the mine plans and sections
- Valuation of the safety factors and suggest corrective measures

The above goal and specific objectives are achieved by adopting the methodology as outlined in the next session.

## **1.2 Methodology**

The above objectives could only be reached if acted upon with a planned approach. The first step towards a goal always starts with knowing everything about it. Thus I began with the literature review. The books, journals, papers proved a rich source of knowledge in this regard and were thoroughly studied and learned.

This was followed by collection of the data from the field. Samples from many sample points were collected and carefully packed and sent to the laboratory for the analysis. Various field visits were also made to know about the actual conditions that exist in the working conditions and which could be included in the study, during the analyses.

The collected samples were undertaken various analysis to know about the sample properties like cohesion, angle of internal friction, density, angle of repose etc. then these sample properties were used in the analyses during the analysis using the software. The factor of safety was determined for different sections of the overburden dump. Some of the slopes were self designed extrapolating the field values and safe workable angle and height of the benches were proposed.

## **1.3 Layout**

This project report is divided into four chapters. Chapter one gives the general introduction, goal and objectives of the report. A critical review of the available literature has been done in chapter

2 followed by tests, analysis and discussions in chapter three. Chapter four concludes the work with further scope.

# CHAPTER: 02

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## **LITERATURE REVIEW**

Background information

Methods of Stability Analysis

Triaxial Testing

Computer Applications



## **CHAPTER 2 LITERATURE REVIEW**

### **2.1 BACKGROUND INFORMATION ON SLOPE PROBLEMS**

#### **2.1.1 Introduction**

In natural, surface topography have never exists in stable stage. By aided of wind and rain, the gravity force moves the hills into the valleys and the valleys into the oceans. Continuous tectonic and intermittent seismic action forms new hills and the cycle of change is continues. However, the construction works locally interrupt the natural cycle of change by excavating into the ground with slope in the natural soil, by filling on top of the ground with slopes outlining the embankment, by covering the ground with impervious blankets, by stepping the surfaces and holding the upper levels with retaining walls, by modifying the groundwater content or level, by storing soil-like materials with bins and so on. In some of these construction works, the strength of natural soil is degraded or the necessary strength of the soil in the relocated position is not provided. Consequently, this failure will lead to a landslide.

The slopes are of two types

1. Natural slopes
2. Man-made slopes

The natural slopes are those that exist in nature and are formed by natural causes. Such slopes exist in hilly areas. The sides of cuttings, the slopes of embankments constructed for taking roads, railway canals etc. and the slopes of the earth dams are examples of finite slopes. The slope length depends on the height of the dam or the embankment.

Slope stability: slope stability is an extremely important consideration in the design and the construction of the earth dam. The stability of natural slope is also important. The result of the slope failure can be catastrophic, including the loss of considerable property and many lives.

Causes of slope failure: The important factors that cause instability in a slope lead to failure are:

1. Gravitational Force
2. Force Due To Seepage of Water
3. Erosion of the Surface of the Slopes Due To Flowing Water
4. The Sudden Lowering Of Water Due To a Slope
5. Forces Due To Earthquakes

The effect of all these movements causes the soil to move from high points to low points. The most important of these forces is the component of gravity that acts in the direction of probable motion.

The effects of flowing or seeping water are generally recognized as very important in stability problems, but often these problems have not been properly identified. It is a fact that seepage occurring within a soil mass causes seepage forces, which have much greater effect than is commonly realized.

Erosion on the surface of the slope may be the cause of the removal of a certain weight, of soil, and may thus lead to an increased stability as far as mass movement is concerned. On the other hand, erosion in the form of undercutting at the toe may increase the height of the slope or decrease the length of the incipient failure surface thus decreasing the length of the incipient failure surface, thus decreasing the stability.

When there is lowering of the ground water or of a free water surface adjacent to the slope, for example in a sudden draw-down of the water surface in a reservoir there is a decrease in the buoyancy of the soil which is in the effect an increase in the weight. This increase in weight causes increase in the shearing stresses, that may or may not be in part counteracted by increase in the shearing strength, whether or not the soil is of low permeability, practically no volume changes will be able to occur except at a slope rate, and in spite of the increase of the load the strength increase may be inappreciable.

Shear at a constant volume may be accompanied by a decrease in the intergranular pressure and increase in the neutral pressure. A failure may be caused by such a condition in which the entire soil mass passes into a state of liquefaction and flows like a liquid. A condition of this type may be developed if the mass of the soil is subject to vibration, for example due to earthquake forces.

General considerations and assumptions in the analysis:

There are three distinct parts in an analysis of the stability. They are:

**1. Testing of samples to determine the cohesion and angle of internal friction.**

If the analysis is for a natural slope, it is essential that the sample be undisturbed. In such important respects as the rate of shear application and state of initial consolidation, the condition of testing must represent as closely as possible the most unfavorable conditions ever likely to occur in the actual slope.

**2. The study of the items which are known to enter but which cannot be accounted for in the computations.**

The most important of such items is the progressive cracking that will start at top of the slope where the soil is in tension, and aided by water pressure, may progress to considerable depth. In addition, there are effects of non-homogeneous nature of the typical soil and other variations of the from the ideal conditions which might be assumed.

**3. Computation**

If a slope is to fail along a surface, all the shearing strength must overcome along the surface which then becomes the surface of rupture.

**2.1.2 Cause of slope failures**

The cause of slope failures may be divided into two categories, which are external and internal failures.

### **2.1.2.1 External**

The external causes of failures are those which produce an increase in the shearing stresses at unaltered shearing resistance of the material. They included steepened of the slope, deposition of material along the edge of slopes, removal of lateral support through the erosive power of streams, glaciers, waves, and long-shore and tidal current, through weathering, wetting, drying and freeze-thaw cycles in surface materials, and earthquake forces.

### **2.1.2.2 Internal**

The internal causes of failures are those which lead to a slide without any change in surface conditions which involve unaltered shearing stresses in the slope material. Such a condition is the decrease in shearing resistance brought about by excess pore water pressure, leaching of salts, softening, breakage of cementation bonds and ion exchange.

### **2.1.3 Short and long term failures**

The study of the stability of natural slope and cuts may be divided into two conditions namely, short and long term conditions. The short term instability is due to non-availability of sufficient time for the dissipation of pore water pressure. However, the long term condition is one in which the pore water pressure gradually adjusts itself in the long run and shows values corresponding to a certain ground water condition.

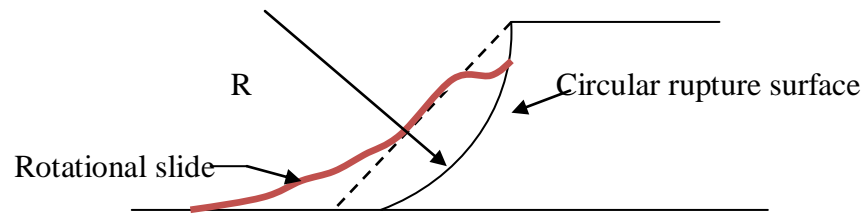
### **2.1.4 Types of Landslides and Slope Movements**

The types of failure that basically occur can be classified as:

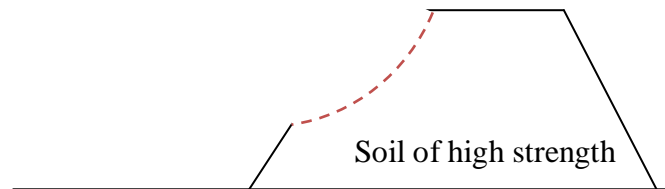
1. Slope failure
2. Toe failure
3. Base failure

In the slope failure, the arc of rupture surface meets the slope above the toe. This can happen when the slope angle  $\beta$  is quite high and the soil close to the toe possesses high strength. Toe failure occurs when the soil mass of the dam above the base and below the base is homogeneous.

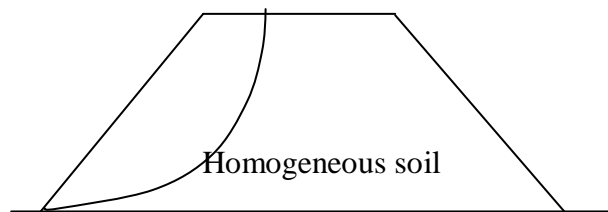
The base failure occurs particularly when the base angle  $\beta$  is low and the soil below the base is softer and more plastic than the soil above the base.



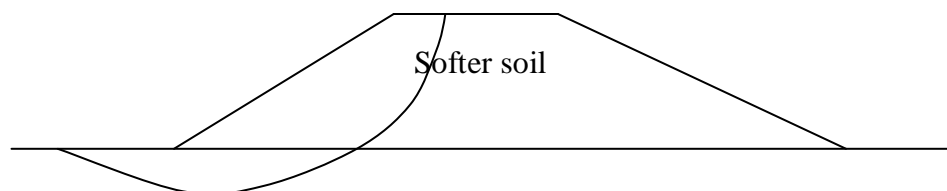
(a) Rotational slide



(b) Slope failure



(c) Toe failure



(d) Base failure

Figure No 1. Various modes of failures of earth dams

## **2.2 METHODS OF STABILITY ANALYSIS OF SLOPES**

The most common type of problem that is encountered widely been the one in which the failure occurs on the curved surfaces. The most commonly used method for the analysis of the homogeneous, isotropic, finite slopes is the Swedish method based on the circular failure surfaces. K.E Petterson first applied the circle method to the analysis of a soil failure in connection with the failure of a quarry wall in Goetberg, Sweden in 1916. A Swedish national commission, after studying a large number of failures, published a report in 1922 showing the lines of failure of most such slides roughly approached the circumference of a circle. It is possible to locate the circle which gives the lowest resistance to shear. This general method has been quite widely accepted as an offering an approximately correct solution for the determination of factor safety of the slope of an embankment and of its foundation. Developments in the method of analysis have been made by many researchers with the result that the satisfactory analysis of the stability of slopes, embankments and foundation by the means of a dangerous circle method is no longer an unduly tedious procedure.

There are several methods based on the method of stability analysis based on the circular arc surface of the failure: The following sections 2.2.1 to 2.2.4 have been taken from (Murthy, V.N.S), 2001.

### **2.2.1 Method of slices**

This method was advanced by the Swedish geotechnical commission and was developed by W. Fellenius. By dividing the mass above an assumed rupture surface of failure into vertical slices and assuming the forces on the opposite sides of each slice are equal and opposite, a statistically determinate problem is obtained, and semi graphical methods have been devised, by which the stability of the mass may be analysed for any given circle. The main objection to this method rests on the fact that most dangerous of the infinite number of possible circles must be found, and thus the graphical procedure must be repeated for a number of circles.

### **2.2.2 Simplified Bishop's Method of Slices-**

This method takes into account the forces acting on the vertical sides of slices in the development of an equation for determining the factor of safety. However, the simplified

equation proposed by bishop does not contain the forces acting on the vertical sides and therefore simplifies the calculations numerous examples have illustrated that this method gives the factor of safety  $F_s$  which fall in the range of equally correct values as determined by the exact methods

### **2.2.3. Friction Circle Method**

It is a very convenient method which takes into account the total forces acting on the whole mass lying above the assumed circular surface of failure. This method eliminates the indeterminate forces that are inherent in the method of slices such as the forces acting on the vertical side of slices.

### **2.2.4. Taylor's stability numbers**

A general solution based on the friction circle method, using a mathematical trial method, was made by Taylor. Stability numbers were obtained from the analysis of friction circle method. Charts have also been prepared giving relationship between stability numbers and the slope angle for various angles of friction. The method is applicable to homogeneous simple slopes without seepage and factor of safety with respect to cohesion has been in the analysis. However, the factor safety with respect to strength may be obtained by trial and error method.

### **2.2.1 Circular surface of failure**

The investigations carried out in Sweden at the beginning of this century have clearly confirmed the surfaces of failure of earth slopes resemble the shape of a circular arc.

When the soil slips along a circular surface such a slide may be termed as a rotational slide. It involves downward and outward movement of the slice of the earth .and sliding occurs along the entire surface of contact between the slice and its base.

#### **2.2.1.1 Method of slices Fellenius Methods.**

Where the slip surface under the study for a slope passes through soil materials whose shear strength is based upon internal friction and effective stress, the method of slices is recognized as a practical means to account for the expected variation in shearing resistance that develops along

the different portions of the assumed slippage arc. The procedure is applicable to slopes in isotropic soils, layered soils and non-isotropic soils.

The procedure involves dividing a mass assumed to be involved in a slope slide into vertical slices. The width for each slide is arbitrarily selected and the slices do not have to be of equal width. For practical convenience, the section of base arc for each slice should pass through across only one soil type and the slice width have to small such that the curve base can be approximated as a straight line.

Figure 2 below shows the free body diagram of the representative slices, serves as a basis for arriving at an expression for determining a slope's factor of safety.

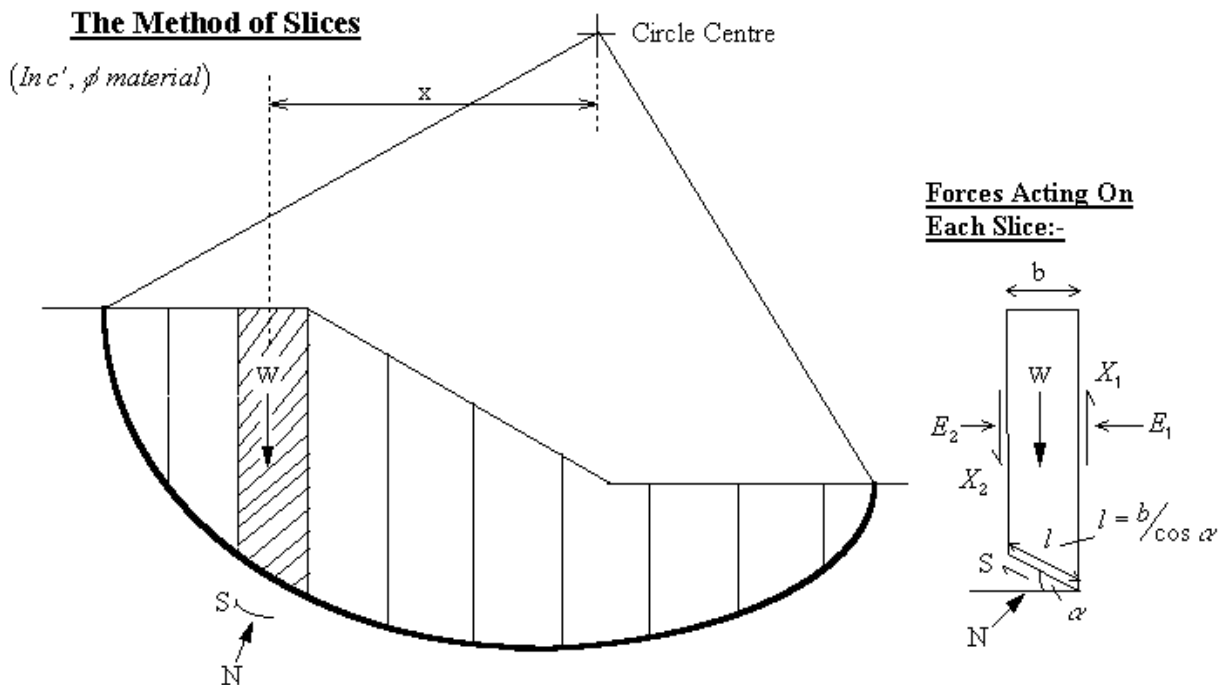


Figure No 2. Free body diagram and mathematical approach for the Fellenius Method of Slices

### 2.2.1.2 Bishop's Method

A method presented by Bishop utilises method of slices and considers forces to be acting on each slices, as shown in the figure. The requirements of equilibrium are applied to the slices



comprising the slope with the factor of safety against a slope failure then being defined as the ratio of the maximum shear strength possessed by the soil on the trial slippage plane to that shearing resistance necessary for equilibrium ( $\tau_{\text{available}}$ ) to that shearing resistance necessary for equilibrium ( $\tau_{\text{mobilised}}$ ), or :

$$FS = \tau_{\text{available}} / \tau_{\text{mobilised}}$$

Shear strength of the soil is given by  $\tau_{\text{available}} = c' + (\sigma - \mu) \tan \Phi = c' + \sigma' \tan \Phi$  ----- (1)

Shearing resistance mobilized is given by  $\tau_{\text{mobilised}} = [1 / (FS)] [c' + (\sigma - \mu) \tan \Phi]$  ----- (2)

The above equation provides the factor of safety for a trial or assumed arc and is obtained by summing slice forces in the vertical direction. the final form of this equation is the result of considering that the total influence of the tangential forces on the side of the slices is small enough to be neglected without having a great effect (i.e. influence of  $\Sigma [T_1 - T_r]$  is small ). The procedure for slope stability analysis that includes incorporating the simplifying the assumption is referred to as simplified bishop method:

$$FS = \Sigma (1/m_a) [c'_b + (W - u*b) \tan \Phi] / (\Sigma \sin \alpha)$$

$$\text{Where, } m_a = (1 + (\tan \Phi \tan \alpha / (FS)) \cos \alpha)$$

The factor  $m_a$  represents a group of terms comparison between the simplified method and a rigorous solution that includes the effects of  $T_1$  and  $T_r$  indicate that the simplified method gives slightly conservative results (i.e the simplified bishop gives the lower factor of safety).

With the bishop method, the factor of safety appears on the both side of the equation to evaluate the stability of the trial failure mass. The procedure for solution involves assuming a value for the factor of safety term on the right side of the equation. When the proper value has been chosen for the trial value on the left side of the equation will equal the value on the right side. Practically a precise agreement is not required to obtain a factor of safety value considered valid for the assumed slip surface. A drawback to the Bishop's method is that it provides unusually high values of factor of safety when the negative values of  $\alpha$  exceed the lower slope area approaches the value of about  $30^\circ$ . This condition can develop where an assumed center of rotation is about the vicinity of the slope's crest or where the deep failure circles are investigated.

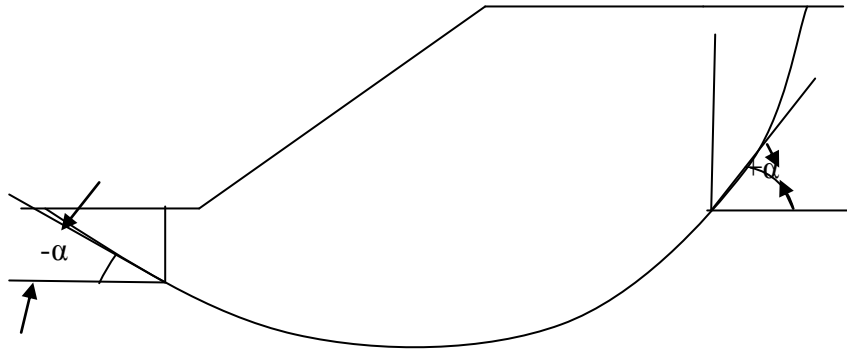


Figure No 3. A slope showing how the circular failure analysis in bishop's method is done.

### 2.2.1.3 Other methods of circular arc analysis

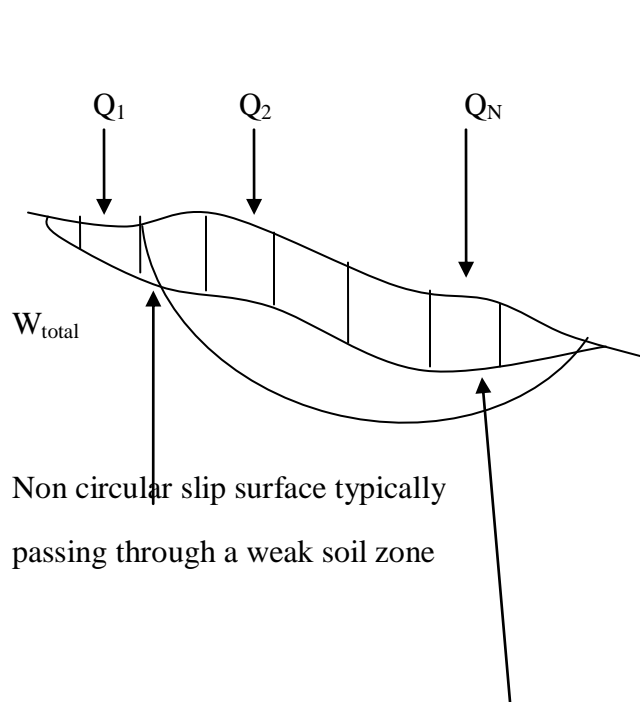
A number of investigations have been developed regarding analytical procedures for slope analyses that are similar in basic approach to the bishop method but differ in handling the inter-slice forces. The two works that are widely referred to are the work of Spencer and Morgenstern-price. The Spencer's analysis assumes that the forces on the sides are parallel. The Morgenstern-price analysis imposes a normal shear and shear forces on the slice sides and also includes the water pressure effects. Both methods satisfy the requirements of equilibrium in regard to the forces and moments that act on the slice. Slope stability evaluations utilizing the mathematically rigorous Spencer and Morgenstern-Price methods retains a practical importance for performing independent checks on the results from complex programs, for use when computer is not available, and for preliminary evaluations or routine checks to determine if a slope requires a regular study.

### 2.2.1.4 Noncircular slip surfaces

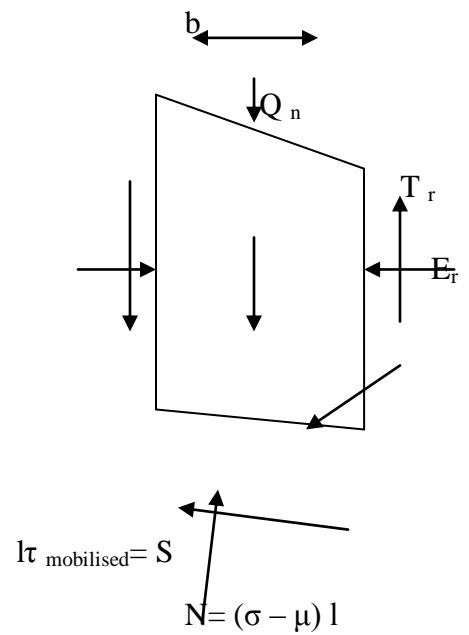
In areas where the topography varies (the slope is not uniform or well defined) or where the subsurface is stratified or non- isotropic, the soil zone most susceptible to a sliding failure may not be properly represented by a circular arc analysis. An analysis that allows such flexibility in

locating the plane of failure is required. The Spencer and the Morgenstern-price methods referred for the circular slips can also be used for the non-circular slip but need a solution by a computer. A generalized method for the analysis of the non- circular slip surface advanced by Janbu is for the computer solution, but the method is also adaptable for the hand calculated solutions when the simplified procedure is utilized. The Janbu method assumes that the forces acting on each of the slice will be as shown in the figure. By applying the requirements of the moment equilibrium and force equilibrium in the vertical and the horizontal directions to each slice and imposing the necessary equilibrium in the horizontal and the vertical directions to each slice and imposing the necessary equilibrium in the horizontal direction to the entire assumed failure mass, an expression for slope factor of safety is written:

$$FS = \frac{\sum (br \sec^2 \alpha)}{(\sum [W + (T_1 - T_r)] \tan \alpha)}$$



Circular failure surface not applicable because it does not concentrate on weaker zones nor identify the earth mass susceptible to sliding



(a) Diagram indicating the need for non-circular analysis of slope stability

(b) Free- body diagram of representative slice, defining forces acting.

Figure No 4. Non-circular slippage plane for the slope stability analysis.

The FS term appears on the both sides of the equation. Trial values are selected and as with the bishop method, the factor of safety has been properly determined when the both sides are in practical agreement.

#### **2.2.1.5 Effect of the Tension Cracks**

Tension cracks developing along the crest or face of a slope (a condition most commonly anticipated where the cohesive soils exist) can influence the slope stability. In an analysis, zero soil shearing resistance is assigned to the section of the slippage plane affected by the tension cracks. If the tension cracks could be filled with water, a hydrostatic pressure distribution assumed to exist in the crack, and this pressure continues to those forces and moments acting to cause slope movement. Frequently, however tension cracks only have a minor influence on the slope's computed factor of safety, but these cracks may provide the opportunity for water to reach otherwise buried earth layers whose strength may be weakened by such exposure, an effect requiring consideration in the slope analysis.

#### **2.2.1.6 Sliding block analysis**

Natural earth slopes consisting of the stratified materials and earth embankment structures on the constructed on the stratified soil foundations can experience failure due to sliding along one or more of weaker layers. Failures of this type often occur when changed conditions in an area cause susceptible layers to become exposed to, or saturated by, water. Exposure to moisture can cause physical breakdown and weakening of some earth materials, such as fine grained sedimentary deposits, and saturation may cause stratum's shear strength to be reduced because of increased pore water pressures.

Where the potential for the occurrence of a block slide is under study, the factor of safety with regard to the shear strength of the soil on the assumed sliding plane is, with no pore pressure effects on the block,

$$FS = (cL + (W \cos \alpha + E \sin \alpha) \tan \Phi) / (W \sin \alpha + E \cos \alpha)$$

Where E can be approximated as  $0.25\gamma_{\text{soil}} Z^2$  for cohesion less soil and  $0.5 \gamma_{\text{soil}} Z^2$  for cohesive soil if the formation of a tension crack along the top of the slope permits the development of water pressure in the crack and the slippage zone, can be described as:

$$FS = (cL + (W \cos \alpha - F_u + F_w \sin \alpha) \tan \Phi) / (W \sin \alpha + F_w \cos \alpha)$$

Where  $F_w$  is the force due water pressures in the tension crack, equal to  $0.5\gamma_{\text{water}} Z^2_{\text{water}}$  and  $F_u = 0.5\gamma_{\text{water}} W_{\text{ater}} L$ .

Sections of soil embankments have known to fail by translation along a weak foundation zone or layer, the force responsible for movement responsible for movement resulting from lateral soil pressure developed within the embankment itself. In the case of the earth dams, the zone of the slippage may develop only after the dam has impounded water for a period, with seepage through the eventual slippage zone being responsible for weakening to the extent that a failure can occur.

The upstream as well as the downstream zones could be studied for stability. though the effect of water on the upstream embankment increases the weight  $W$ , and the lateral pressure of the impounded water for a period oppose block translation the uplift force is considerably greater for upstream zones. As with other categories of sliding failures, determine the size and location of the section most susceptible to movement is typically a trial and error procedure, because the most critical zone is not always obvious.

### 2.3 Triaxial Testing Apparatus for Determination of Sample Properties

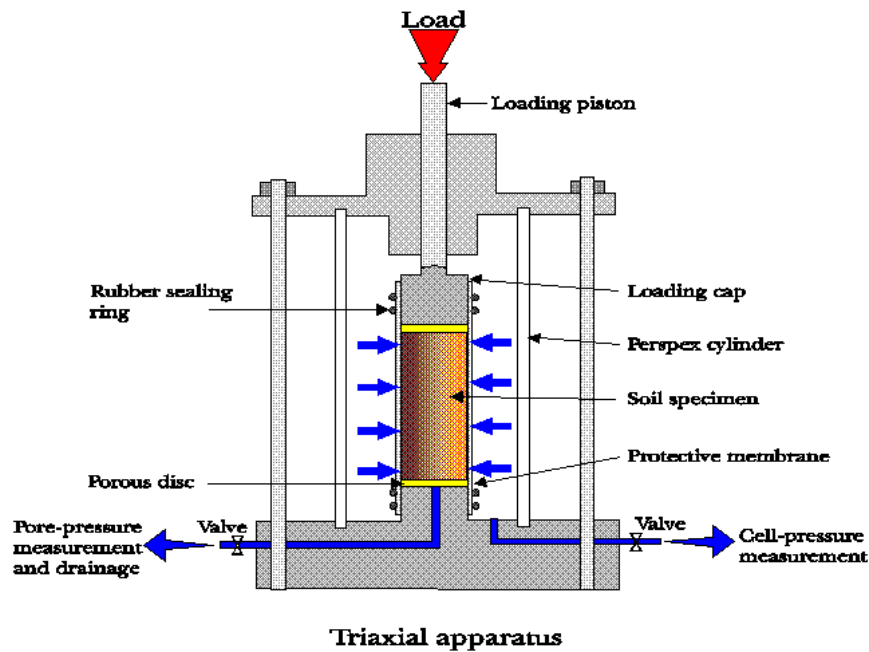


Figure No 5. A typical triaxial test apparatus

This is achieved by following the procedures laid in ASTM D 2850 and ASTM D 4767. In brief it consists of the sample being cut or reconstructed in a cylindrical form, covered by an impermeable membrane, subjected to a hydraulic pressure within a special cell and then tested to failure under an axial load. The purpose of the test is to ascertain the shear strength of the sample and determine the relationships between stresses and strains. The advantage of the Triaxial Test over the Direct Shear Test is in the recreation of real conditions: the failure plane is no longer conditioned by the apparatus itself but develops along the plane of lesser resistance within the sample.

The control of drainage and pore pressure allows the study of the effect fluids have of the mechanical properties of the solids in the sample. The triaxial test also allows radial strain of the sample under load, a feature not present in consolidation tests performed with odometers. Therefore the triaxial test may be useful in identifying deformations where the Poisson Ratio of the material is of importance.

### **2.3.1.1 Composition of the Apparatus**

The Triaxial Test Apparatus may be composed in various ways, in order to ensure the most rational choice of component parts we recommend that the following guide is followed step by step so as to identify the apparatus which most fully satisfies all tests likely to be encountered.

### **2.3.1.2 Sample Dimensions**

The most frequent sample diameter is 38.1 mm (1.5 inch). Larger diameters may be necessary if the sample contains coarse grains. Small diameter samples are preferred with fine grained soils so as to reduce the time needed for drainage and consolidation.

### **2.3.1.3 Sample Preparation**

Samples of cohesive soil are normally taken from undisturbed specimens by either boring or turning on a lathe. The former method is acceptable in soils of medium consistency whilst the latter is preferred for soft or hard material. With the boring method, as well as a Sampling Tube of suitable diameter with relative accessories, it is advisable to have a Hand Extruder to extrude the sample from the tube. A special Electric Lathe is available for turning samples to the required diameter. Naturally, the lathe must be equipped with Support Platens of the same diameter as that of the required sample. Once the sample has been turned or bored it can be cut to its correct length (two times its diameter) with level and parallel faces by placing it in a **Two-Part Split Mould** and trimming the ends with a trimming knife or wire saw. To reconstruct sand samples a **Three-Part Split Former** of suitable diameter is used.

### **2.3.1.4 ELEMENTS USED WITHIN THE TRIAXIAL CELL**

The Triaxial Test may be programmed so as to allow or exclude the hydraulic connection between the inside of the sample with the ambient outside the triaxial cell or with special measuring instruments. Such connections require the use of special drainage mediums around the sample, in particular: Porous Discs on the top and bottom of the sample and Filter Drains around its sides. However, if the sample must be isolated, the bottom porous disc is replaced by an impermeable Base Disc whilst the upper porous disc is removed. In each case the sample is placed on a Pedestal and a



Top Cap is placed on top of the sample. These elements will have the same diameter as the sample. To isolate the sample from the water within the triaxial cell, it is covered with a very thin Membrane made of natural rubber (of appropriate diameter) which is placed over the sample using a Suction Membrane Stretcher and a water-tight fit is guaranteed at the junction with the pedestal and top cap by using Sealing Rings of appropriate diameter.

### **2.3.2 TRIAXIAL CELLS**

The triaxial cell is a water-tight container with hydraulic connections at the base and sliding load piston in the top. The cell can be readily opened to allow the positioning of samples and cell accessories. The pedestal on which the sample sits is interchangeable with pedestals of different diameter provided that these are compatible with the cell itself. Three different cell sizes are available; the choice of cell is determined by the size of sample to be tested. The Triaxial Apparatus may include one or more cells (normally three). Multiple cell system is justified inasmuch that a complete Triaxial Test normally requires three samples to be tested under different confining pressures. Therefore, considerable time savings can be achieved by using three cells in series, particularly if the test includes sample saturation and long consolidation times before the samples are subjected to axial loading.

### **2.3.3 CONSTANT PRESSURE SOURCES**

Normally, the confining pressure around the sample is furnished by pressurised water, thus the triaxial cell must be connected to a system capable of providing pressurized water. This system must also be capable of compensating for eventual volume changes of the sample by providing or receiving the corresponding volume of water without change in water pressure. The system must also be capable of controlling the water pressure to a high degree of accuracy. These systems are commonly known as Constant Pressure Sources and are available in various forms based on different working principles and thus have differing characteristics.

The **Bladder Air-Water System** more modern and efficient. This system envisages the use of a normal **Air Compressor** and an **Interface Cylinder** where a thin rubber membrane separates the air and water and prevents their mixture whilst allowing both mediums to maintain equal pressures.

The pressure is controlled by a special valve on the compressed air feed line, whilst it is read by a Manometer on the line of compressed water. The accuracy and response of this system depends upon the quality of the pressure regulating valve; long term reliability is achieved by ensuring the supply of clean dry air to the valve, therefore it is advisable to provide an **Air Filter** and **Dehumidifier with Refrigerator Cycle** to the air supply line.

The advantages of the Bladder Air-Water system are many; it is compact, extremely easy to use, readily expandable, and able to compensate for large volume changes. It should be noted that long interruptions to electric mains supply can cause problems to this system; indeed if the tank of the compressor is allowed to discharge there will inevitably be a decompression of the system as a whole. A simple and economic pressure source is provided by the **Air-Water Cylinder and Foot Pump System**. In reality this system should not be considered as a serious alternative to the aforementioned system due to the fact that its limited capacity of compensation demands frequent adjustments to be made by the operator. However, this system may prove valid if only rapid tests are to be performed (Unconsolidated, Undrained). The apparatus consists of an **Air-Water Cylinder** which acts in the same way as an autoclave, a **Foot Pump** to pressurize the cylinder, a **Pressure Gauge** with relative mounting **Bracket and Clamp** and a set of **Flexible Nylon Hoses** for connection to the triaxial cell. The number of independent constant pressure sources required in a triaxial system may vary and will depend upon the number of triaxial cells in use, the type of tests to be performed, the degree of flexibility of the system and the amount of money to be invested.

In all cases each cell will require at least one independent constant pressure source to pressurise the water which surrounds the sample in the triaxial cell.

However, it is advisable to provide the cell with a second independent pressure source so as to furnish back pressure. In a relatively modest system with limited flexibility, one source of back pressure may be sufficient, this being connected to each cell as the need arises. More refined systems will require separate back pressure sources for each cell in use. The need for back pressure is due to the frequent necessity to saturate samples and eliminate even the smallest air bubbles trapped within the hydraulic circuit connected to the inside of the sample. In practice the technique used is to increase the back pressure and cell pressure appropriately so as to force any air to dissolve into the water without creating a difference in pressure between the inside and outside of the membrane

surrounding the sample. In this way it is possible to saturate the sample without giving act to the consolidation of the sample itself. Once saturation has been achieved variations in pore pressure may be accurately monitored during the axial loading of undrained tests, thus providing data for the correct interpretation of the test. Naturally, back pressure should not be provided by the air-water cylinder and foot pump system because the process of air dissolving into the water will occur within the cylinder and not where it is necessary, that is within the sample.

### **2.3.4 LOAD FRAME**

Once the operations of hydraulic pressurisation and consolidation have been completed, the triaxial cell is placed under a Load Frame which has the function of applying an increasing axial load on the sample up to sample failure. The characteristics of the load frame are very demanding unless only rapid tests (unconsolidated, undrained) are to be made. In fact, the increase in strain in certain slow tests is minimal and expressed in terms of micro-meters per minute. On the other hand, it is necessary to be able to regulate the rate of strain applied to the sample within a very large range and, ideally, fully variable so as to allow the correct selection of strain for each particular test. Another requisite of the load frame is the accuracy and continuity of strain rate independently of the forces encountered. The load frame should be selected in function of the maximum load force required which in turn will depend upon the consistency of the material to be tested and sample diameter. A 10 kN Load Frame is more than sufficient for 1.5" samples. The 50 kN Load Frame is recommended for larger diameter samples or if the load frame is to be used for other laboratory tests (e.g. C.B.R.). The 100 kN Load Frame is used for large triaxial cells and special tests. Three-place version (50 kN) is particularly interesting: it allows simultaneous testing of 3 samples, thus saving time.

### **2.3.4 MEASURING INSTRUMENTS**

Instruments for measuring load and axial strain will need to be applied to the load frame; if analog readings are sufficient for these two parameters then normally a Load Ring and Dial Gauge are used. If digital readings are required, Electronic Sensors described elsewhere in this catalogue are used. The capacity of the load measuring instrument should be compatible with the loads to be measured which will depend upon the resistance and diameter of the sample. It may well be necessary to purchase various capacity load measuring instruments.

As a general rule, if only 1.5” samples are to be tested, a load measuring instrument with a capacity of 200 kgf is normally sufficient. The travel of the axial strain measuring instrument is also dependent on the diameter of the sample and should not be less than 20% of said diameter.

Other measuring instruments may be connected to the triaxial cell, these include:

Pressure Sensors

Volume Change Sensors

The former are used to measure pore pressure during sample saturation and during axial loading in undrained tests. The latter are used to measure volume changes of the sample during consolidation or during axial loading in drained tests. For rapid unconsolidated undrained tests on clay samples these instruments are not normally used. In the past, pressure measurements were normally made within instruments known as “Null Indicators” which consisted of small transparent siphons containing mercury. One side of the null indicator is connected to the triaxial cell whilst the other side is connected to manometers and a volumetric pump.

This pump is used to form a back pressure to equalise the pressure from the triaxial cell, the correct pressure is that which keeps the mercury in the correct position within the siphon, the resultant back pressure, which equals the pore pressure, is read on the manometers. In practice the use of this instrument demands great care and lack of attention by the operator or misuse can easily lead to the loss of important test data and the annulment of the test. For this reason, nowadays preference is given to Electronic Pressure Transducers connected to Digital Displays. The transducer is fitted to the triaxial cell via a De-airing Block, and the pressure is expressed in engineering units directly on the display. When the triaxial apparatus is connected to a Data Acquisition System, the use of these electronic transducers is compulsory. The number of transducers necessary is normally one per each cell in use; however one transducer with relative de-airing block may be transferred from one cell to another.

## **2.4 COMPUTER APPLICATIONS IN SLOPE STABILITY ANALYSIS**

### **2.4.1 Introduction**

As computer applications are gradually become common in many fields, engineers also keep track to take advantage of computer to solve engineering problems. There are several advantages of using computerized solution for engineering problems, there are as below:

- The amount of time to perform an analysis can be greatly reduced.
- Computer solutions can be more detailed than hand calculations. Performing a solution manually often requires many simplifying assumptions.
- The solution process may be less error-prone. For example, unit conversion and the rewriting of equations to solve for any variable, where hand calculation often tend to have mistakes, while a well-tested computer program can be avoid these error.
- The solution is easily documented and reproducible.
- Because of the speed and accuracy of a computer model, more comparisons and design trials can be performed in less time than a single computation done by hand. This results in the exploration of more options, which eventually leads to better and more efficient designs.

This part of literature review presents the review of several on the shelf software for slope stability analysis. There are Slope/w and T/slope.

### **2.4.2 Slope/w Software**

Slope/W is the leading software product that used for computing the factor of safety of earth and rock slopes. With Slope/W, engineer can analyze both simple and complex problems for a variety of slop surface shape, pore-water pressure conditions, soil properties, analysis methods and loading conditions. Besides that, by using limit equilibrium, Slope/W can model heterogeneous soil types, complex stratigraphic and slip surface geometry, and variable pore-water pressure condition using a large selection of soil models. Analyses can be performed using deterministic or probabilistic input parameters. Stresses computed by a finite element stress analysis may be used in addition to the limit equilibrium computation for the most complete slope stability analysis available.

### **2.4.3 T/Slope**

T/Slope is an easy-to-use program that helps civil engineers with the slope stability analysis. This software is designed for limit equilibrium slope stability analyses of noncircular slip surfaces by either the Spencer or Morgenstern and Price Method. In order to start analysis, the user only needs to specify the potential slip surface and soil properties along that slip surface, then the program will search for the critical seismic coefficient in which this seismic coefficient reduces the factor of safety to unity.

### **2.4.4 Overview of FLAC/SLOPE**

FLAC/SLOPE is a program that designed specifically to perform factor of safety calculation for slope stability analysis. This program is a mini version of FLAC and operated entirely from FLAC's graphical interface (the GIIC). It also provides rapid creation of model for soil and/or rock slope and solution of their stability condition.

FLAC/SLOPE also provides a full solution of the coupled stress/displacement, equilibrium and constitutive equation. Given slope geometry and a set of material properties, the system is determined to be stable or unstable. By automatically performing a series of calculations with different properties, the factor of safety is found corresponding to the point of instability and the critical failure surface can be located.

Here is how a generated mesh in a model developed for Flac/Slope looks like

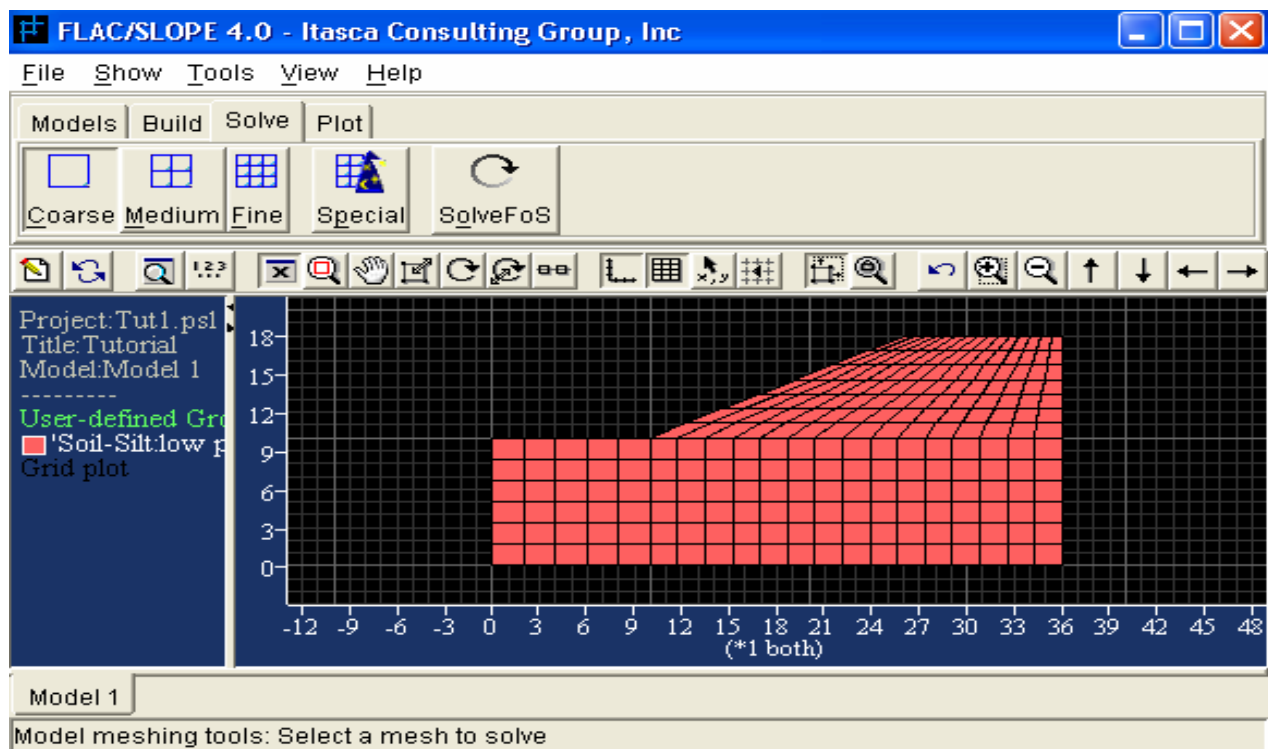


Figure No 6. An example of how simple mesh is generated.

And this how the final failure profile result looks like

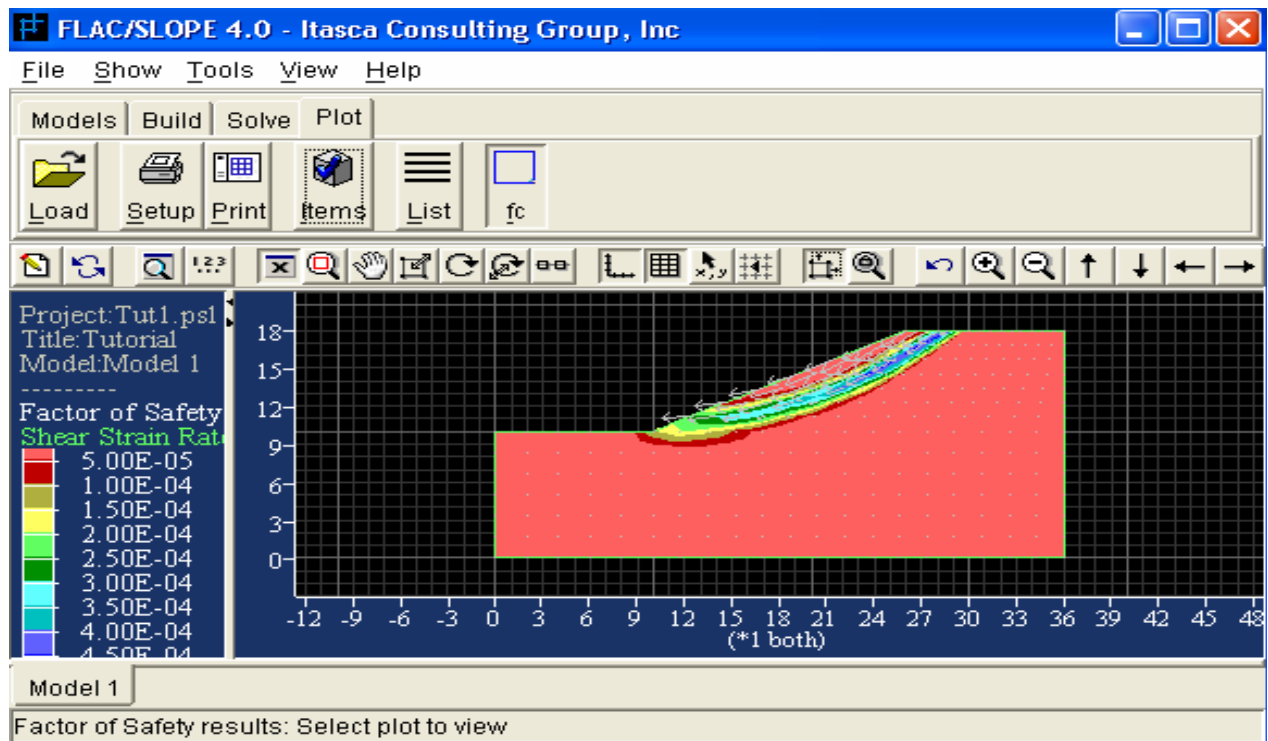


Figure No.7 Failure plot for coarse grid model with friction angle and cohesion included in the factor of safety calculation.

## 2.4.5 Overview of GALENA

**GALENA** is a simple, user-friendly yet very powerful slope stability software system so you can simulate complex geological, groundwater and external force conditions without wrestling with frustrating computer instructions. **GALENA** has been developed by geotechnical engineers for practical use in the field. It was tested on a wide variety of earth and rock slopes, dams and cuttings. **GALENA** incorporates three methods of slope stability analysis so you can assess a wide range of ground stability problems in both soils and rocks.



- The **BISHOP** Simplified method determines the stability of circular failure surfaces.
- The **SPENCER-WRIGHT** method for either circular or non-circular failure surfaces.
- The **SARMA** method for problems where non-vertical slices are required or for more complex stability problems.

With all three methods available in one package, you can tackle any problem in a variety of ways without stopping to load a new program.

This how an analysis on the galena software would look like

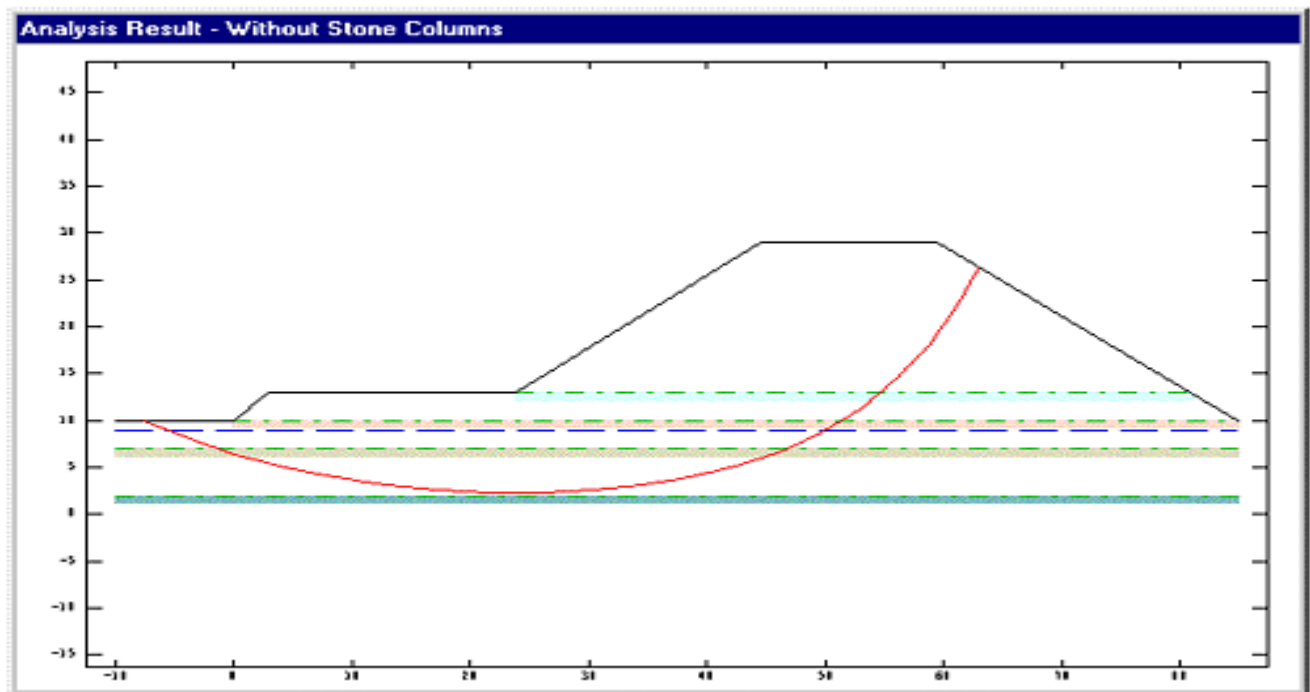


Figure No.8 An analysis using GALENA

# CHAPTER: 03

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## **MATERIALS AND METHODS**

Data Collection

Data Analysis

## **CHAPTER 3**

### **3.0 MATERIALS AND METHODS**

#### **3.1 Data Collection**

The objective of the investigation was to stabilize the dump slope so that it facilitates safe operations. The typical analysis ingredients are cohesion, angle of internal friction and density. These data represent the engineering properties of the area under investigation. In this study pertinent data from the area were so collected that they represent the whole area. The samples were taken from 32 locations. Samples were collected so as to represent the worst environmental conditions i.e. rainy and summer season when the moisture % keeps on varying. This affects the stability of the dumps. The samples were taken at about depth of 3 mts from the surface of the dumps. Firstly, a cylindrical structure is hammered into the surface up to the stipulated depth and then the container with soil sample was carefully taken out, immediately packed into a plastic gunny bag so as to avoid interference of atmospheric conditions and brought to the laboratory. It was ensured that the sample preserved its virgin state.

In the laboratory the triaxial tests are carried out on the samples and then the important parameters such as cohesion and angle of internal friction are analyzed from these tests. The density and the moisture contents are also calculated. These values are grouped into dry values (devoid of moisture), and saturated values (containing moisture). The analysis is done separately for the dry and the saturated samples as the moisture causes reduction in the strength and that factor of safety has to be studied.

#### **3.2 Data Analysis**

There are many dedicated softwares available for the analysis of the slope stability. But two of the more acclaimed softwares in this field were used i.e. GALENA and FLAC/*Slope* for the analysis of the various sections. Flac/*Slope* was more useful taking into account the overall stability. The GALENA was more useful taking into account individual bench stability as well non- homogeneous terrain.

FLAC/Slope gives the flexibility in choosing the various modes of failure like the Mohr-Coulomb failure, Hoek and Brown Failure, whereas the GALENA is flexible in choosing the type of analysis that has to be taken i.e. bishop's method, Spencer's method, Sarma's method.

Both these softwares were used simultaneously for analysis and the results were obtained.

# CHAPTER: 04

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## **TEST RESULTS AND DISCUSSIONS**

## CHAPTER 4

### 4.0 TEST RESULTS AND DISCUSSIONS

Stability problems on the slope arise due to high in-situ stresses that are created within. Thus to solve this problem we must know about the various in-situ stresses that exist, but since finding out the in-situ stresses as well as its direction is not possible at all times and sometimes not feasible at the site, hence we tend to find out the factors that might give rise to the shear failure. The factors namely cohesion( $c$ ), angle of friction ( $\phi$ ) and unit weight are important in funding out the possible shear failure. The samples were collected at depths varying from 0.2 mts to 2.85 mts from the surface. The samples were collected from different points, collected as per established standard procedure, sealed and sent to the laboratory for determination of the properties. Figure No.9 shows the sectional view of the dumping area. The average values of the test results as given below were used for the slope analysis. Slopes were examined in terms of the sections of the whole dump. Each section was evaluated using the FLAC/*Slope* and GALENA for the overall angle of safety. Same was also carried out for individual benches given separately. Also it was done for the change in the angle of benches (proposed) as well as that for the factor of safety.

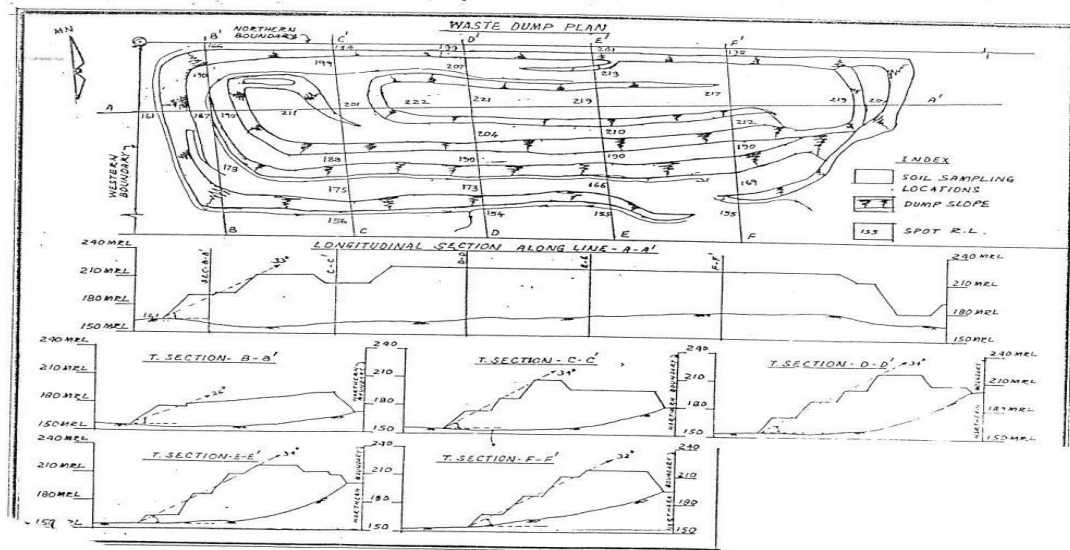


Figure No 9. Sectional view of the dumping area



Figure No 10. The view of the slope at the waste dump (water seepage related sliding observed at few locations)

Analyses were also carried out using the least values regarding the maximum height, no of benches and slope of the individual bench. Bench height was taken to be 30 mts. in the proposed design. It was found out that the factor of safety for the current sections were in the range of 1.75 to 2.0. And the factor of safety for the average values of material properties with the proposed dimension would be in the range 1.3 to 1.6.

The values of the dry and the wet samples after the analysis were as follows:

➤ Drained Samples:

$$c = 46.3 \text{ kN/m}^2, \phi = 31.48, \rho = 1578.48 \text{ kg/m}^3$$

➤ Saturated/ Undrained Samples :

$$c = 11.9 \text{ kN/m}^2, \phi = 16.6, \rho = 2077 \text{ kg/m}^3$$

Table No.1 Material properties at various sample points as determined in laboratory

Sl. N	Section	Density (kg/m <sup>3</sup> )	Cohesion(c) (Pa)	Internal friction Angle ( $\phi$ )
I	A-A'	1480	30000	32.7
		1400	70000	33.6
II	B-B'	1470	76000	23.6
		1710	91000	31.7
		1590	64000	33.9

The figure numbers give the details of the analysis done using the software FLAC/slope. The various zones marked with different colors symbolise surfaces that are weak and are prone to failure.



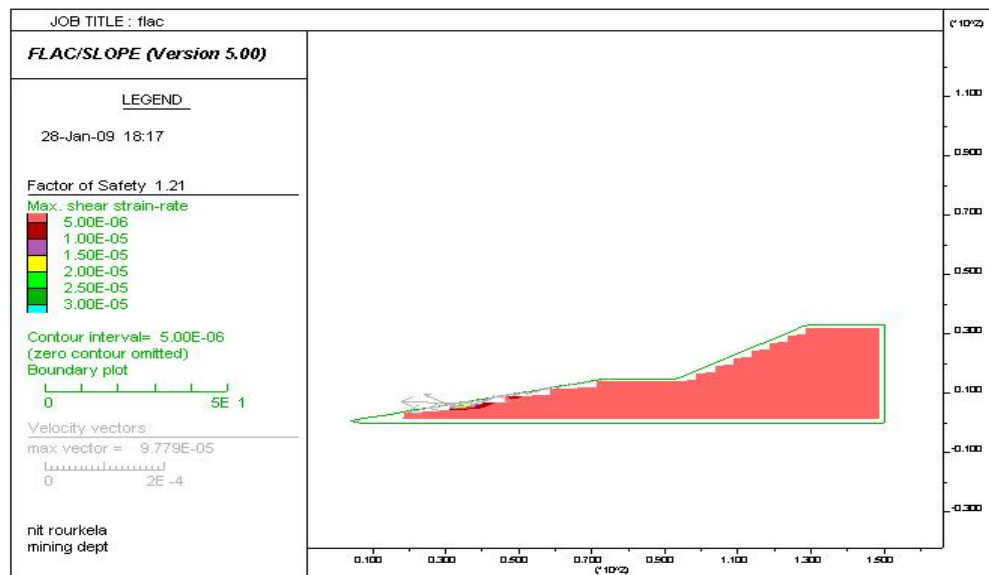
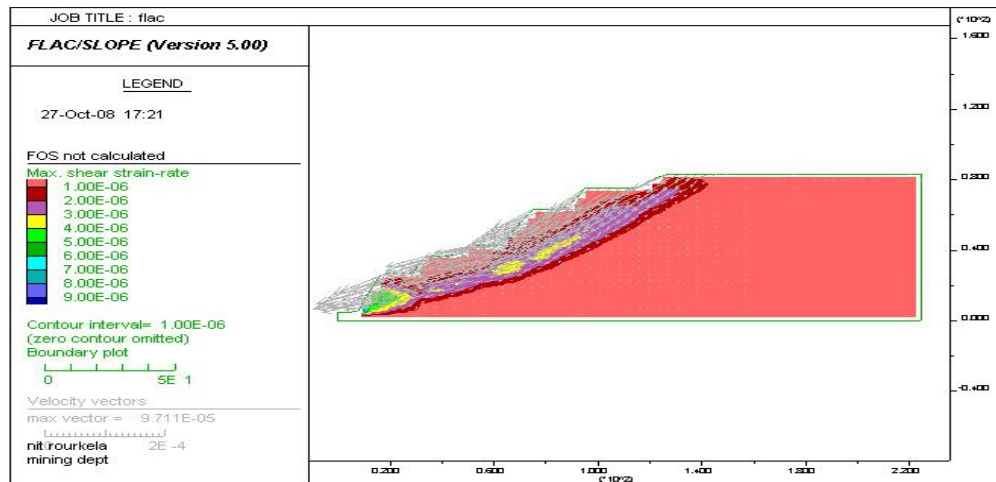


Figure No 11. Analysis of the models with using FLAC/ slope

Table No.2 Sectional analysis using the dry values

Sl.no	Section	Used			Calculated factor of safety
		Cohesion(in kN)	Angle of friction	Density (in g/cc)	
1	A-A'	46.3	32.3	1.578	2.53
2	B-B'	46.3	32.3	1.578	2.51

Table No.3 Sectional analysis using the wet values

Sl.no	Section	Used			Calculated factor of safety
		Cohesion(in kN)	Angle of friction	Density (in g/cc)	
5	A-A'	11.9	16.6	2.077	1.40
6	B-B'	11.9	16.6	2.077	0.53

Under the saturated conditions one of the values obtained is lesser than 1.0, which indicates unstable slopes but the field visit inferred no such result. This means that the not completely saturated conditions exist in the field. Also there might be other factors affecting the stability, which could not be included in the analysis.

To make sure how much height could be attained for the slope and what angle could be safe, further analysis was done taking the saturated values and varied heights and angles. The results that were obtained have been shown below.

Table No.4 Proposed values using the saturated values

Sl.no	Height	Slope angle	Used			Calculated factor of safety
			cohesion	Angle of friction	Density	
1	15	26	11.9	16.6	2.077	1.06
2	20	26	11.9	16.6	2.077	1.05
3	25	37	11.9	16.6	2.077	0.85
4	30	37	11.9	16.6	2.077	0.87

It was observed from field visits that the slopes were more or less stable. However the numerical modeling gives opposite results i.e. the slope is unstable. It is inferred that the material properties as obtained from the laboratory tests do not reflect the actual data existing in the field or the material exhibit different property at field. It is also concluded that the data considered for numerical modeling is an underestimation of the field values. Hence the material properties values were changed so as to economize the slope and following results were obtained.

Table No.5 Analysis with the 20% increase in the actual saturated values

Sl.no	Height	Slope angle	Used			Calculated factor of safety
			Cohesion	Angle Of Friction	Density	
1	15	26	14.2	19.2	24	1.23
4	20	26	14.2	19.2	24	1.22
7	25	26	14.2	19.2	24	1.16
8	25	30	14.2	19.2	24	1.11
11	30	26	14.2	19.2	24	1.29

Table No. 6 Analysis with 40% increase in the saturated values

Sl.no	Height	Slope angle	Used			Calculated factor of safety
			cohesion	Angle of friction	Density	
1	25	31	16.8	22	26	1.29
2	30	26	16.8	22	26	1.50

On the basis if these results some conclusion and recommendations were given. The analysis did not include the creation of the phreatic surface, the inclusion of which could have yielded different results.

# CHAPTER: 05

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## **CONCLUSION AND RECOMMENDATION**

Conclusion

Recommendation

## **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATIONS**

#### **5.1 Conclusion**

Based on the various analyses available following recommendations have been made to ensure stability of the slope

- a) The slope of the existing dumping yard do not exhibit any major failure except in cases where water seepage or presence of boulders. Those cases are also observed to be at a few locations and do not cover a large area.
- b) The existing slope have safety factor in the range of 1.75 to 2.00 with slope angles between  $25^0$  and  $35^0$ .
- c) The safety factor with the proposed angle of slope of  $37^0$  is 1.3.

#### **5.2 Recommendation**

In this investigation a few aspects of slope stability as slope of the bench, height of bench as well as angle of internal friction, cohesion and density of the material has been determined. However there are many factors that affect the slope stability such as ground water table, grain size of the dumped material, etc. So it is strongly recommended that the following may be taken into consideration in future.

- a) The samples have not been taken to the complete depth; the samples have been taken just from 3 mts depth and are not exact simulation of the field conditions.
- b) Proper provisions have to be made to channelize the rain water by construction of the suitable drains surrounding the dump yard.
- c) The dumps have to be segregated properly i.e. according to the size of the disposed material. The fines being dumped separately, and the boulders separately.
- d) The inclusion of the phreatic surface should have been done.

e) Slope monitoring should be carried out regularly to predict the slope angle and height with variation in material properties.

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